FET BASED DIAMOND BIOSENSORS

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Abstract

FET based diamond biosensors have been demonstrated by utilizing surface functionalizing techniques. pH sensitivity is obtained on diamond SGFETs with O or NH_2 terminated channel. The sensitivities of 50 mV/pH have been obtained on diamond SGFETs with O and NH_2 terminated channel, in contrast with the no pH sensitivity on that with H-terminated channel. FET based biosensors whose channel has functionalized by the biomolecules such as DNAs and enzymes have been realized on diamond SGFETs.

Introduction

Electrochemical sensors are suitable to environmental monitoring, clinical trials and also critical care situations, because of fast response, portability, small samples for detection and simple testing processes. Challenging researches are proceeding with development of various kinds of sensors based on electrochemical electrode or semiconductor device fabrication with micro-electromechanical technologies in wide variety of materials. Especially, diamond is attractive attentions of sensor materials due to its superior material properties. Factors such as wide electrochemical potential window, chemical and physical stability, high thermal conductivity and biocompatibility are expected to realize the low-noise and high-sensitive sensors or integrated sensor allay with high reliability.

Recently, FET type chemical and biosensors have been reported on H-terminated diamond [1-4]. Compare to Si-ISFETs, diamond solution-gated FETs (SGFETs) work without interlayer on the surface as shown in fig. 1, because the penetration of the ions in the solution are suppressed. As a result, fast response, stability of surface potential and high sensitivity are realized.

pH sensitivity on functionalized diamond FETs

Surface of the diamond deposited by chemical vapor deposition is terminated by hydrogen. This surface shows the p-type semiconductivity with high carrier density of 10^{13} cm^{-2} within 10 nm from the surface, which is easily controlled by the applied bias and suitable as the channel of FETs. In case of diamond SGFETs, the surface carriers are controlled by not only the applied bias of electrolyte solutions, but also the adsorbed specific ions, protonations or deprotonations.

Diamond SGFETs with the completely H-terminated surface channel has no sensitivity on pH change because the surface functional groups (C-H) are not protonated or deprotonated in wide variety of pH change. On the other hand, the pH sensitivity of SGFETs can be obtained by the partially NH_2-O-terminated channel with UV irradiation in ammonia solution or atmosphere, because C-O and C-NH_2 are protonated or deprotonated in the solutions. The absolute value of the gate potential preserving constant drain current of diamond SGFET decreased approximately 50 mV/pH from pH 2 to pH 10 and the gradient of that obeyed the Nernstian response as shown in fig. 2. The time response of pH sensitivity is superior to that of Si based ISFET, because penetration of ions such as K^+, Na^+ and Ca^{2+} are vanished in diamond. The hysteresis width is approximately 1 mV, which value is one order of magnitude lower than that of membranes used in Si-ISFETs (fig.3).

Diamond Biosensors

Several types of diamond biosensors such as urea, glucose and DNA sensors, have been demonstrated by means of biomolecules functionalized diamond surfaces.

Urea-sensitive diamond SGFETs operate based on the biocatalyzed decomposition of urea by urease. This decomposition changes the surrounding pH, which is occurred on the channel surface, and NH_2 functionalized surface can detect this pH change as shown in fig. 4.

The charges on DNAs are also detectable on diamond SGFETs. When the negatively charged DNAs are hybridized on the complementary single strand DNAs immobilized on diamond surface, the surface potential of the diamond SGFETs bends upward, as a result, increase of the drain current and the positive shift of the threshold voltage of diamond SGFET are observed as shown in fig 5. The difference between complementary and non-complementary target DNAs has been detected by the real time shift of the gate voltage.

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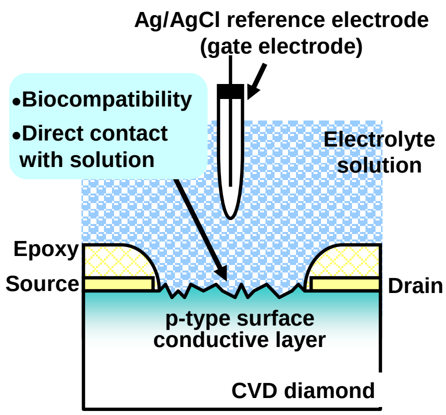

Fig.1 Diamond SGFETs

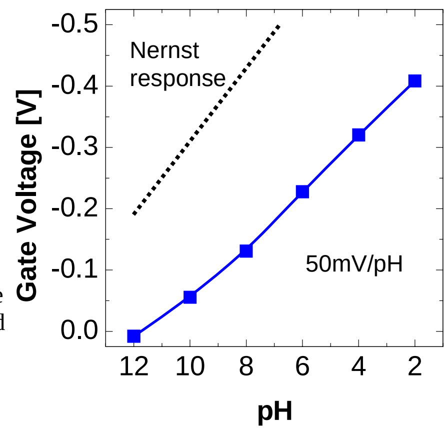

Fig.2 pH response of NH_2 terminated diamond SGFETs

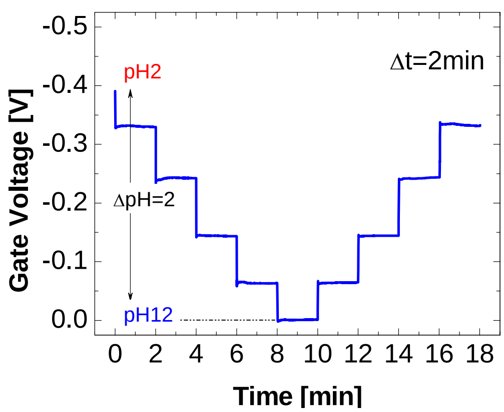

Fig.3 Hysteresis characteristics of a diamond SGFETs

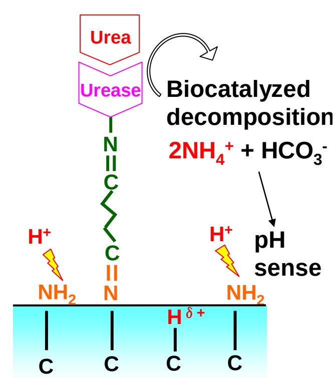

Fig.4 Urea sensing by an urease immobilized SGFET.

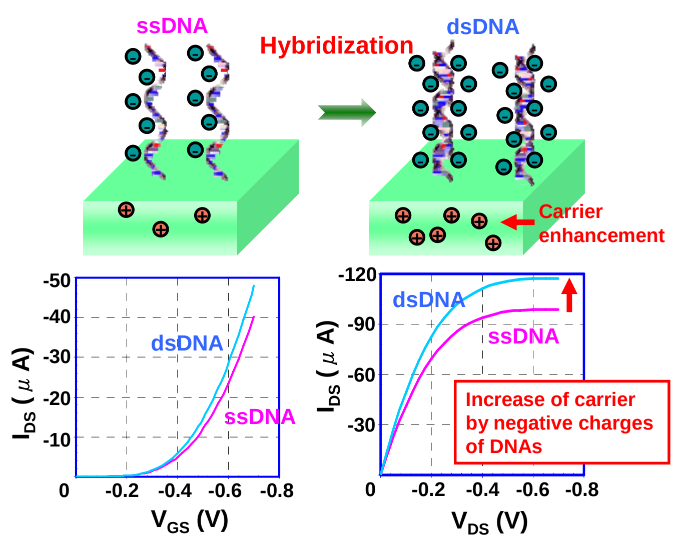

Fig.5 Hybridization of DNA sensed by diamond SGFET, where a single strad DNAs are immobilized on the diamond surface..